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LEVEL II

**DECISION ANALYSIS:
ENGINEERING SCIENCE OR CLINICAL ART?**

by

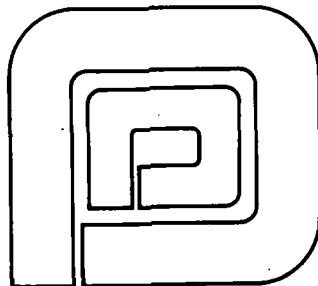
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SUMMARY

This paper examines two philosophical poles concerning the structuring of decision-analytic models. The engineering science approach uses complex, engineering-like models to link the decision maker's alternatives to his or her value structure; a computer then calculates the decision-analytic answer. The clinical art approach develops a simple model that structures the decision maker's thoughts concerning a decision in such a way that the critical issues in choosing one alternative over another are readily apparent. Three exemplary applications of each philosophical pole are used to demonstrate that at the extremes, the work of practitioners can be categorized as we describe.

A discussion of the two practical extremes of decision analysis is then presented. In this discussion, dichotomous characteristics are assigned to the decision maker, the decision, and the analyst's constraints to portray conditions under which either the engineering science approach or the clinical approach would be more effective in producing appropriate insight and understanding. Then the implications of each approach are described in terms of the tools and procedure the decision analyst uses. Finally, the selection of the approach the decision analyst might use in any given application is graphically portrayed and discussed in terms of the points made in this paper.

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DECISION ANALYSIS:
ENGINEERING SCIENCE OR CLINICAL ART

1.0 INTRODUCTION

Decision analysis is a logically consistent, prescriptive method that can be used by decision makers to quantitatively evaluate the courses of action available in a particular decision situation. The major theoretical elements of decision analysis are probability theory and utility theory as assembled by Savage, De Finetti and others in the 1950's under the title decision theory. In the late 1960's the name decision analysis was coined to describe the application of decision theory to actual decisions faced by corporate and government decision makers. This application of decision theory required the acknowledgment that capturing the judgmental expertise of the decision maker and his associates is a prerequisite to aiding the decision maker through analysis. That is, any analysis restricted to hard, measured data would be insufficient in detail and scope to provide a decision maker with useful insight as to which decision ought to be preferred. Decision analysis, therefore, relies heavily on judgmental considerations of probabilities, preferences, and decision model structure to provide the decision maker with a quantitative, coherent, logical analysis of available options.

Different approaches exist for identifying and organizing the factors of a decision into a decision model structure. They have in common their dependence on the insight and skill of the decision analyst who questions the decision maker extensively to identify the key elements of the decision problem and to formally represent the informal concepts which exist primarily in the mind of that decision maker.

The decision analyst is guided in this inquiry by the type of inquiry system or mind-set he or she has adopted or been trained to use. This paper isolates and discusses two extreme approaches to decision analysis which are representative of two different inquiry systems. One approach views decision analysis as an engineering science and focuses the analysis around the decision process that relates the alternatives and uncertainties to outcomes. The other approach views decision analysis as a clinical art and establishes a structured platform for dialogue and debate among the decision maker and his/her experts.

Before further defining and discussing these two approaches, however, we would like to examine the overall objectives of a decision analysis. The best way to do this is to consider what decision analysts have said in the literature about the purpose of these analyses. First, Howard (1974) describes the logical decision:

When this has been done, when we've carried out this procedure and have established your preferences, the values you place on outcomes, your attitude toward time, your attitude toward risk (and there is a methodology for doing all of this), when we have established the models necessary for the decision you're making and have assessed probabilities as required on the uncertain variables, then we need nothing but logic to arrive at a decision. And a good decision is now very simply defined as the decision that is logically implied by the choices, information, and preferences that you have expressed. There is no ambiguity from that point on--there is only one logical decision.

Next, several decision analysts (Barclay et al. 1977), colleagues at Decisions and Designs, Inc., (DDI) have written:

It should be emphasized that in no sense does decision analysis replace decision makers with arithmetic or change the role of wise human judgment in decision making. Rather, it provides an orderly and more easily understood structure that helps to aggregate the wisdom of experts on the many topics that may be needed to make a decision, and it supports the skilled decision maker by providing him with logically sound techniques to support, supplement, and ensure the internal consistency of his judgments.

Finally, Keeney and Raiffa (1976) state:

Decision analysis looks at the paradigm in which an individual decision maker (or decision unit) contemplates a choice of action in an uncertain environment. The approach employs systematic analysis, with some number pushing, which helps the decision maker clarify in his own mind which course of action he should choose.

The objective of the decision analyst is thus to assist the decision maker in arriving at good decisions. This assistance takes the form of a structured representation (model) of the decision problem based upon the tenets of decision analysis: alternatives, consequences/outcomes and uncertainties, for which numerical values are elicited to determine quantitatively the best decision. However, as decision analysts are gaining experience in applying their decision-aiding techniques, most are finding that the notable improvements in decision making come not from the numerical

conclusions of the model but from the insight and understanding that the decision maker obtains by participating in the analysis. We wish to stress here that the role of the decision analyst is to facilitate the decision maker's insight and understanding of the problem at hand.

This paper is organized to proceed from the definition of the two divergent approaches to decision analysis (engineering science and clinical art) in Section 2.0 to the description of three exemplary applications of each approach in Section 3.0. Finally, a discussion of the two practical extremes of decision analysis is presented in Section 4.0. In this discussion, dichotomous characteristics are assigned to the decision maker, the decision, and the analyst's constraints to portray conditions under which either the engineering science approach or the clinical approach would be most effective in producing appropriate insight and understanding. Then the implications of each approach are described in terms of the tools and procedures the decision analyst uses. Finally, the selection of the approach the decision analyst might use in any given application is graphically portrayed and discussed in terms of the points made in this paper.

2.0 DEFINITIONS

Both the engineering science and clinical art approaches to decision analysis attempt to separate and structure the decision maker's alternatives, uncertainties, and values. The two approaches differ, essentially, in the way they relate these alternatives, uncertainties, and values to each other quantitatively to calculate the best decision. That is, model structuring is the difference. The engineering science approach focuses upon the decision process through which the alternatives and uncertainties can be related to the outcomes. This is depicted in Figure 2-1. Thus, the knowledge and information of the decision maker and other experts are used to quantify not only the uncertainties and values of the decision maker but also the process underlying the decision problem that relates the way the alternatives impact these uncertainties and values.

In contrast, the clinical art approach emphasizes a structured analysis but does not use complex mathematical models to display all of the values and uncertainties of the decision in a systematic way. With this approach the decision maker can discuss, probe, and place in proper perspective each aspect of the decision. Thus, the clinical art approach can be summarized as the construction of a structured platform for dialogue and debate among the decision maker and his associates as illustrated in Figure 2-2.

In summary, then, the engineering science approach can be said to use the tenets and axioms of decision analysis in conjunction with a mathematical approximation of the real decision process in order to provide the decision maker with feedback concerning the best decision. The tenets of decision analysis are maintained in the clinical art approach and are used to develop a simple structural model

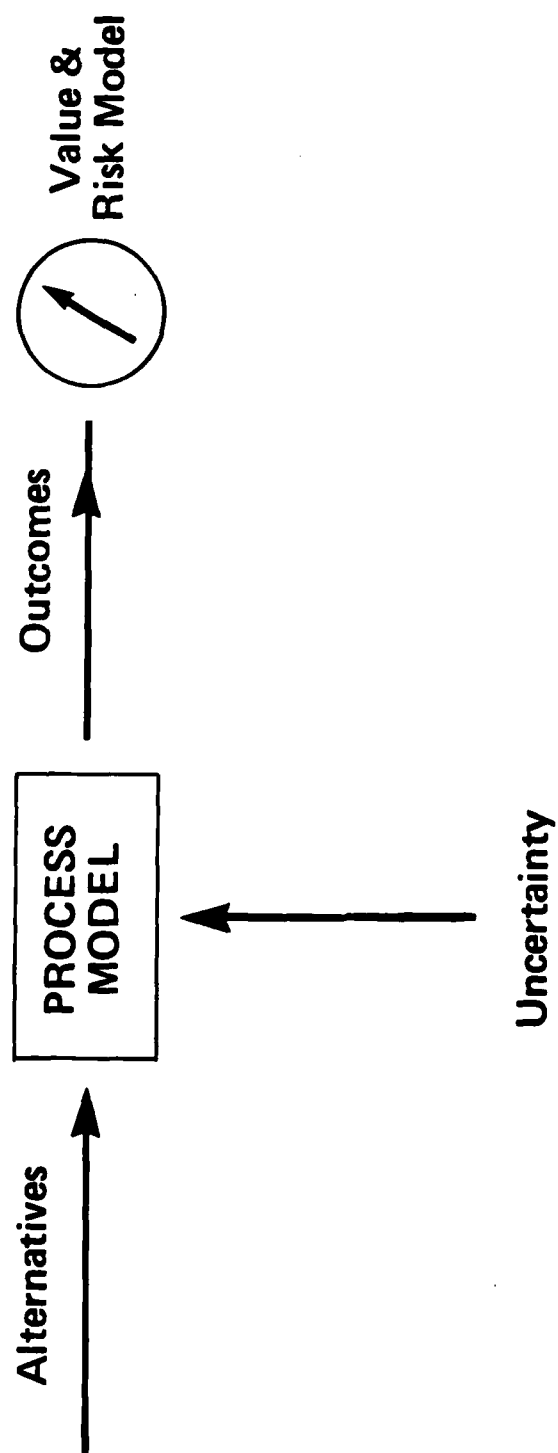


Figure 2-1
ENGINEERING SCIENCE APPROACH

of the factors entering into the decision. However, the decision process and the full range of analysis (including time and risk preference and explicit uncertainties) are often downplayed if they preclude providing the decision maker with insight and understanding.

3.0 EXEMPLARY APPLICATIONS OF THE ENGINEERING SCIENCE AND CLINICAL ART EXTREMES

This section provides three exemplary applications of both the engineering science and clinical art approaches to practical decision analysis. The discussion of each application is directed only to those characteristics that best highlight why the particular application can be described as either engineering science or clinical art.

3.1 Applications of the Engineering Science Approach

3.1.1 Mexican electrical system - The first engineering science application involves a decision-analytic model of the Mexican electrical system. This analysis was conducted by the decision analysis group at SRI for the Mexican government. The decision-analytic effort adhered to Howard's protocol of pilot, prototype, and production phases, and was based upon a computer simulation model of the Mexican electrical system shown in Figure 3-1 and described by Matheson (1974):

The pilot phase demonstrated the need for elaborate models that were capable of capturing the complexities of the electrical system problem. Thus, during the prototype phase, a modular system of computer programs was constructed. This modular system facilitated the implementation of changes that would naturally occur in the transition of the production phase and permits the appropriate module to be easily updated as the nature of the electrical system changes in the future.

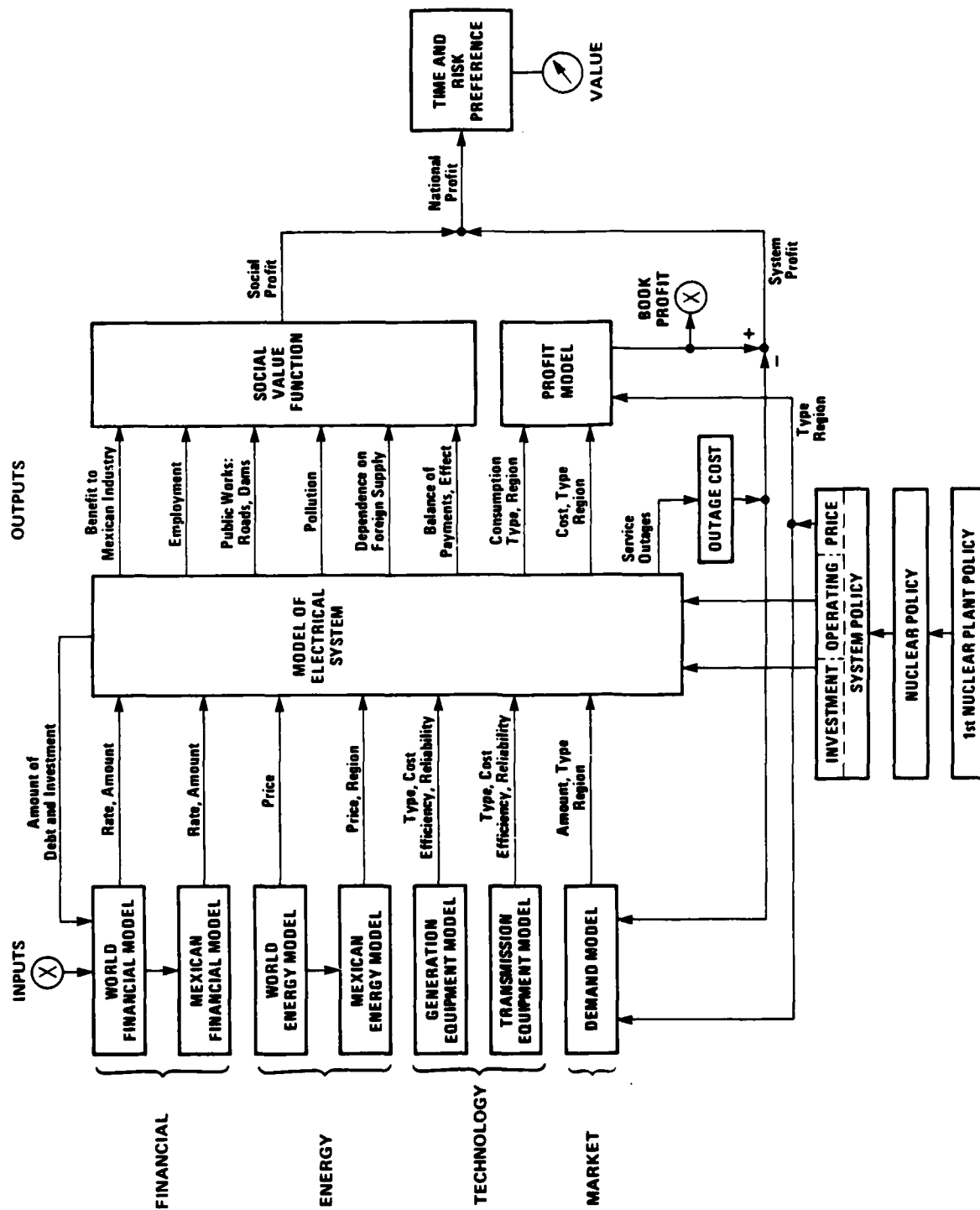


Figure 3-1
A DECISION ANALYSIS MODEL OF THE MEXICAN ELECTRICAL SYSTEM

This electrical system model is fed by submodels involving finances, energy, technology, and the market place:

The financial model characterizes the terms at which capital is available from both domestic and world financial institutions and markets, as a function of the profitability, debt, and equity of the power utility. The energy model describes the price of all potential fuel - such as oil, natural gas, and uranium - as well as the availability of other energy sources - such as water power - over the time period considered in the analysis. Similarly, the technology model characterizes the availability and prices of various types of generation equipment. Finally, the demand model characterizes the electrical demand growth over time, ideally as a function of the price charged for electrical service.

At the bottom of the figure is the policy stating the conditions under which the first nuclear plant should be installed. The figure shows that this policy must be embedded in the general nuclear policy, which in turn is embedded in the system's investment, operating, and pricing policy.

In addition, Mexico's nuclear policies were taken into account. The value model for the decision analysis consisted of a monetary system profit as well as the "social profit" made up of numerous attributes such as employment and balance of payments. These social profit attributes were costed out so they could be added to the system profit for each alternative. In addition, both time and risk preference were important in this power system planning decision for the Mexican government and so these were modeled as well. This computer based model was constructed

by a team of SRI's decision analysts and Mexico's engineers in about one year. This model is continuing to be used by Mexican officials to determine both the type and location of new power plants that should be installed in Mexico.

3.1.2 SRI-Gulf Energy Model - The second application of the engineering science approach is that typified by the use of the "SRI-Gulf Energy Model." This model is a highly detailed, regional and dynamic model of the supply and demand for energy within the United States. It was developed to aid in a decision-analytic effort of synthetic fuel policy evaluation for the Gulf Oil Corporation. The model is based on a generalized equilibrium modeling methodology for the coordinated decomposition of complex decision or optimization problems involving many resources, time, uncertainty, and multi-attribute preferences. Cazalet (1977) states that the three basic elements of this methodology are:

- (1) processes describing the fundamental submodels,
- (2) a network describing the interactions among the processes, and
- (3) an algorithm for determining the numerical values of all of the variables in the model.

The network structure of the model is shown in Figure 3-2, and Cazalet defines the links between the processes:

The links are expressed as prices and quantities of energy products. Other links in the model that are not shown in Figure 3-2 can express environmental controls and outcomes, the relationship of the energy sector to the economy, the constraints on prices or quantities. At the top of this network are processes describing the end-use demands for energy, and at the bottom are processes describing primary resource supply.

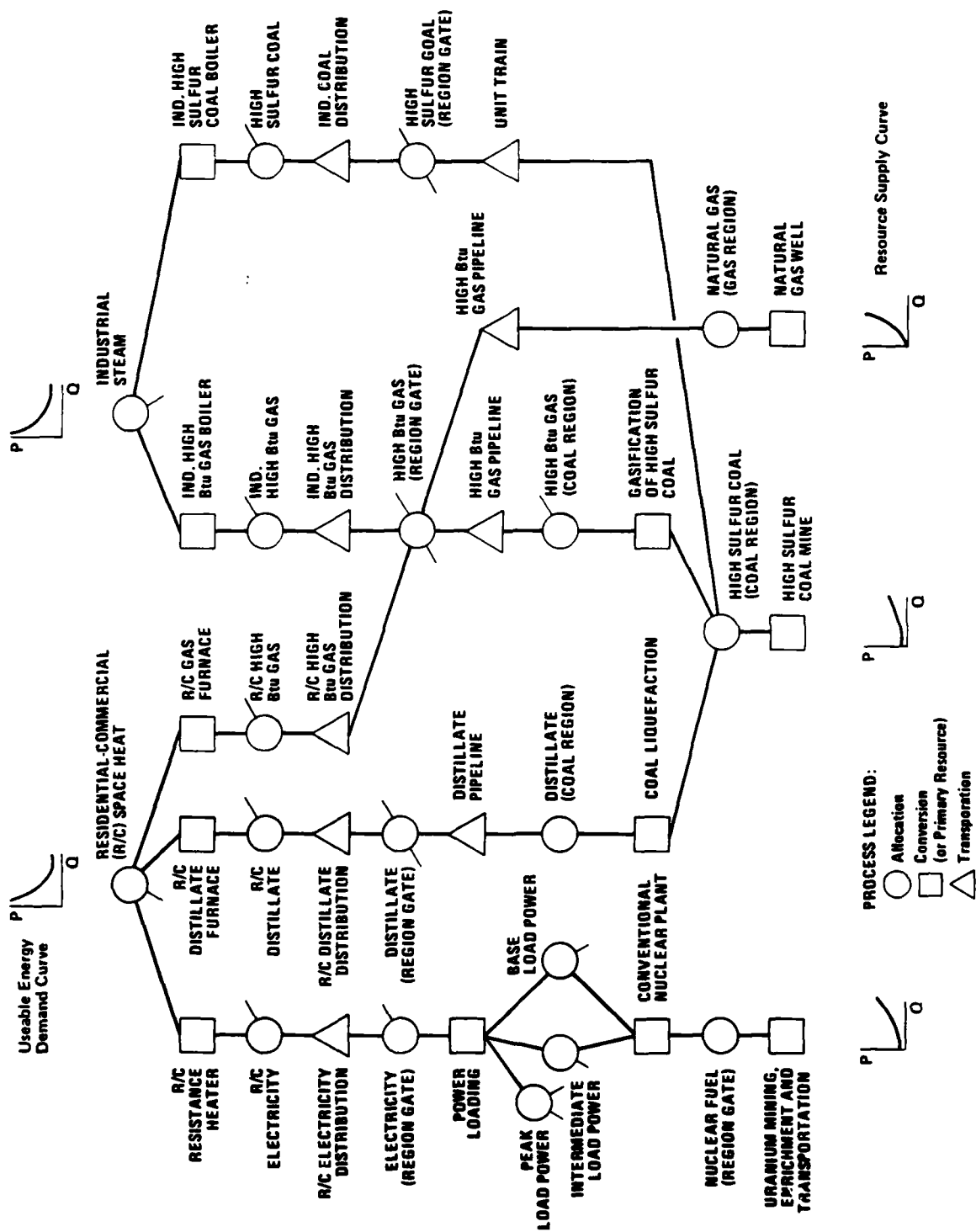


Figure 3-2
NETWORK STRUCTURE OF THE SRI-GULF MODEL

In between is a network of other processes describing market behavior, conversion and transportation in the entire energy system. The actual SRI-Gulf model network currently has about 2,700 processes of the types illustrated in Figure 3-2.

To solve this generalized equilibrium model, an iterative algorithm is used on a computer to iterate up and down the network of demand and supply curves until an equilibrium solution is reached. This model is continually being improved as it is used to assist more decision makers.

Decision analysts have also used this equilibrium model to assist government decision makers in commercialization decisions about prioritizations for research and development on energy supply techniques. In one such application with the Synfuels Interagency task force, the optimum alternative, as indicated by the SRI-Gulf energy model, was very dependent on which of several plausible scenarios was being postulated. Since the SRI-Gulf energy model is too cumbersome to be used when there is significant uncertainty about scenarios, much of the model's rich detail had to be sacrificed for further analysis. So regional and product details of the SRI-Gulf Energy Model were aggregated, and the resultant model was used in a standard decision tree analysis. (See Manne et al. 1979 for further description.)

3.1.3 Xerox Corporation manufacturing facilities decision - the final engineering science application was conducted by decision analysts within the Xerox Corporation. In this case a task force composed of representatives from manufacturing, marketing, planning, finance, facilities, and service organizational units was charged with recommending a decision on construction of new manufacturing facilities for copier/duplicator consumables. The analysts developed a simulation model to help analyze the decision and served as

a communication channel for the many representatives on the task force. The model structure for this decision analysis is depicted in Figure 3-3. This simulation model consisted of several mathematical submodels, as shown in the boxes of the figure. For example, the consumables demand model was a set of differential equations. The competition model began as a decision-analytic model of Xerox competitors and was later modified to be a satisficing model (for a discussion of the theory of satisficing, see Simon 1971). The entire analytical process consisted of a base-case simulation which showed one clearly dominant decision, a series of sensitivity analyses and, finally, several scenario analyses. The sensitivity and scenario analyses indicated that the dominant decision remained so except under the most extreme cases.

3.1.4 Summary - Each engineering science application is characterized by a complex mathematical model of the decision process. In each case the decision analyst claimed that complex models were useful to provide both the decision analyst and the decision maker sufficient insight into the decision so that a "good decision" would be made.

3.2 Applications of the Clinical Art Approach

3.2.1 System acquisition decision - The first application involving the clinical art approach to decision analysis can be categorized as a system acquisition decision. In these decisions, the decision maker--in this case, the government--has several well-defined alternative system designs from which to choose. The decision maker has already decided that a system of some sort is needed to do a specific function or functions.

In the case of the government, an evaluation board is assembled to recommend the preferred system. However, this board must then submit its recommendation to higher level decision makers before the ultimate decision is made. The

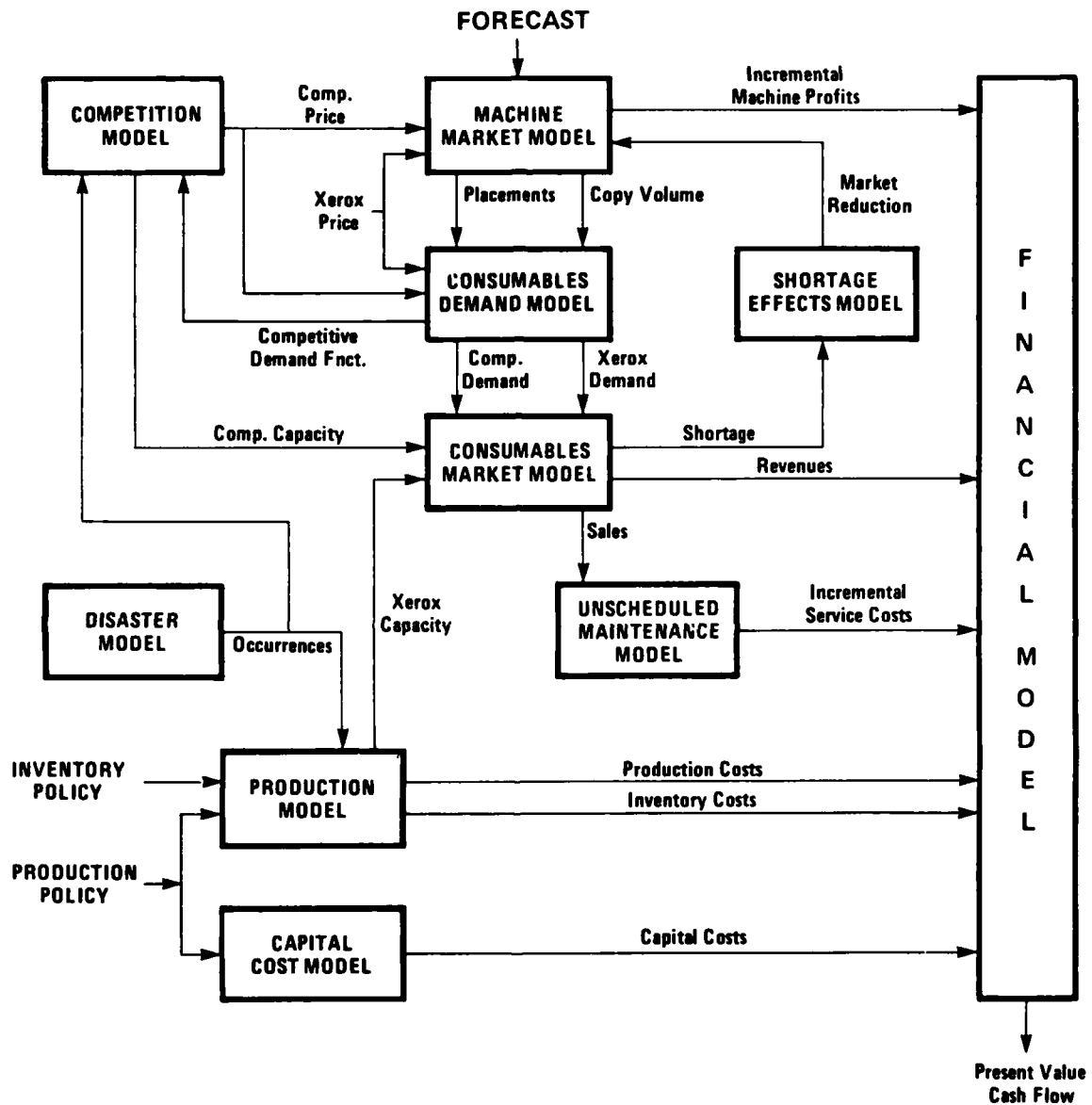


Figure 3-3
A DECISION ANALYSIS OF XEROX COPIER CONSUMABLES

evaluation board is composed of segmented groups of experts who prepare evaluation reports of the alternatives relating to their particular areas of expertise. Each report examines the specific issues that decision makers thought should be evaluated in order to discriminate between the systems in contention.

After the issue reports have been written, groups of them are summarized by appropriate experts at ascending levels of the hierarchy until a final summary of issues is prepared for the decision makers. In some cases, the evaluation board may use a quantitative scale to evaluate each alternative on each issue. A ten-point scale is the most common, but experience has shown that these scales provide very little discrimination among the alternatives when a final weighted average across all scales is produced. (This quantitative approach can be described as a linear additive multi-attribute utility model.)

The government has developed rules to maintain the ethical validity of the evaluation boards; they basically state (1) that the weights in any quantitative approach must be decided independently of the specific issue evaluations and (2) that the experts performing the issue evaluations of the system alternatives must compare each alternative with a standard reference measure and not with the other alternatives. Clearly, any multi-attribute utility analysis which obeyed these rules would have to be conducted prior to seeing the alternative systems and therefore would be suspect since there are always critical differences among alternatives that are never foreseen until the actual alternatives are examined in detail.

Another potential problem with a linear additive utility model is that it may be a poor approximation of the decision maker's true values for the situation at hand. Finally, one issue that is almost always identified is the

technical risk associated with alternative systems. This issue is clearly in conflict with the axioms of decision analysis since it does not properly separate probabilities from values.

The clinical art approach to this type of decision is to accept the bounds that have been put upon the decision process by the government and use a multi-attribute utility model framework. But in addition, the experts are required to justify their numerical evaluations with concise reasons for the scores they have assigned to the alternatives on each issue. The multi-attribute scores and weights and the reasons for them are then stored in a computer that serves as an information retrieval system. This information retrieval system is used by decision makers at any level of the decision-making process to investigate 1) which issues discriminate most effectively among the system alternatives, and 2) the sensitivity between the individually determined weights and scores that have been used to reach the weighted score calculated for each system.

A typical multi-issue structure used in this system acquisition decision process is illustrated in Figure 3-4. The survivability category clearly contains issues which interact heavily and for which a linear additive approximation might be quite poor. However, the decision analyst, by providing an information retrieval system to the evaluation board, enables the board to give the higher level decision makers, upon whom the ultimate authority rests, clearer distinctions among the alternatives from which they have to choose. This structured information system can then be used to impart the critical details of the evaluation to the decision makers so that they are partially immersed in the evaluation. By using this structure, the decision makers can identify the critical differences among the

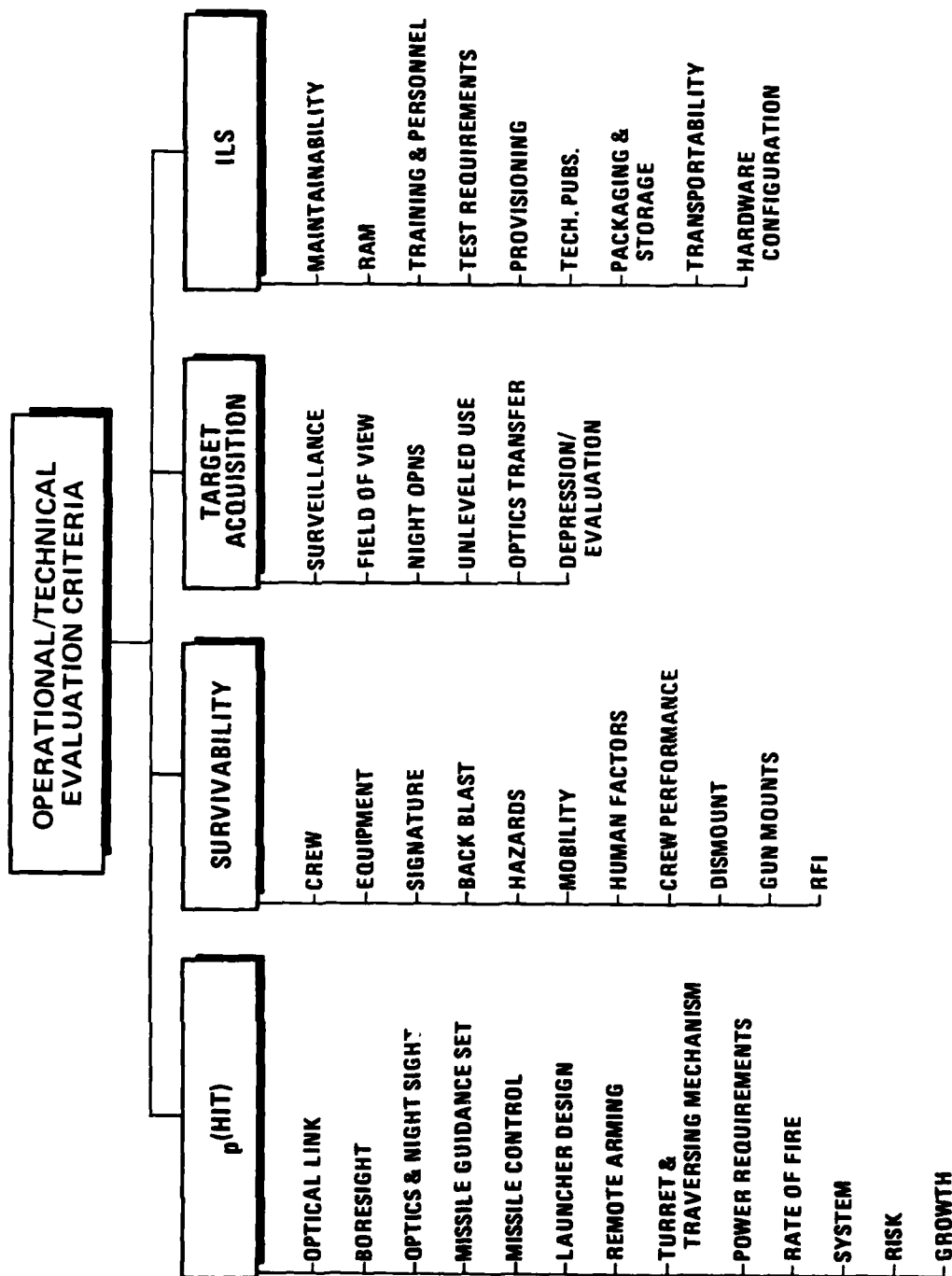


Figure 3-4
SYSTEM ACQUISITION DECISION

alternative systems for their decision--a decision that can be made completely independently of the numerical scores that were developed for the additive model.

3.2.2 DOT tanker safety negotiation - The second application of the clinical art approach to decision analysis is one in which DDI decision analysts assisted the Coast Guard and the Department of Transportation in an international negotiation on tanker safety and pollution prevention. The negotiation was conducted in February 1978 as a result of demands by the United States that stricter regulations be developed to prevent the pollution and safety hazards associated with oil tankers. Approximately one hundred nations participated in the negotiation; they considered a number of tanker safety and pollution prevention alternatives that included such things as "segregated ballast," "double bottoms," and so on. Finally, twelve criteria were identified that the countries commonly used to describe their preferred treaties. The three dimensions (countries, alternatives, and criteria) made explicit in the decision-analytic aid are shown in Figure 3-5.

During the first iteration of this decision analysis, a quantitative scale for each of the twelve criteria was constructed so that any negotiated alternative could be scored on twelve scales. Then two initial alternative treaties, "status quo" and "President Carter's initiative," were scored on each of the criteria. Finally, individual value weights for the countries were developed so that the two alternatives could be evaluated from the point of view of each participating country.

During the second iteration, refined value weights were established for each country; new alternatives were developed; and two submodels for "world oil" and "oil in own waters" were structured so that more accurate evaluations could be made for the alternatives on these two criteria.

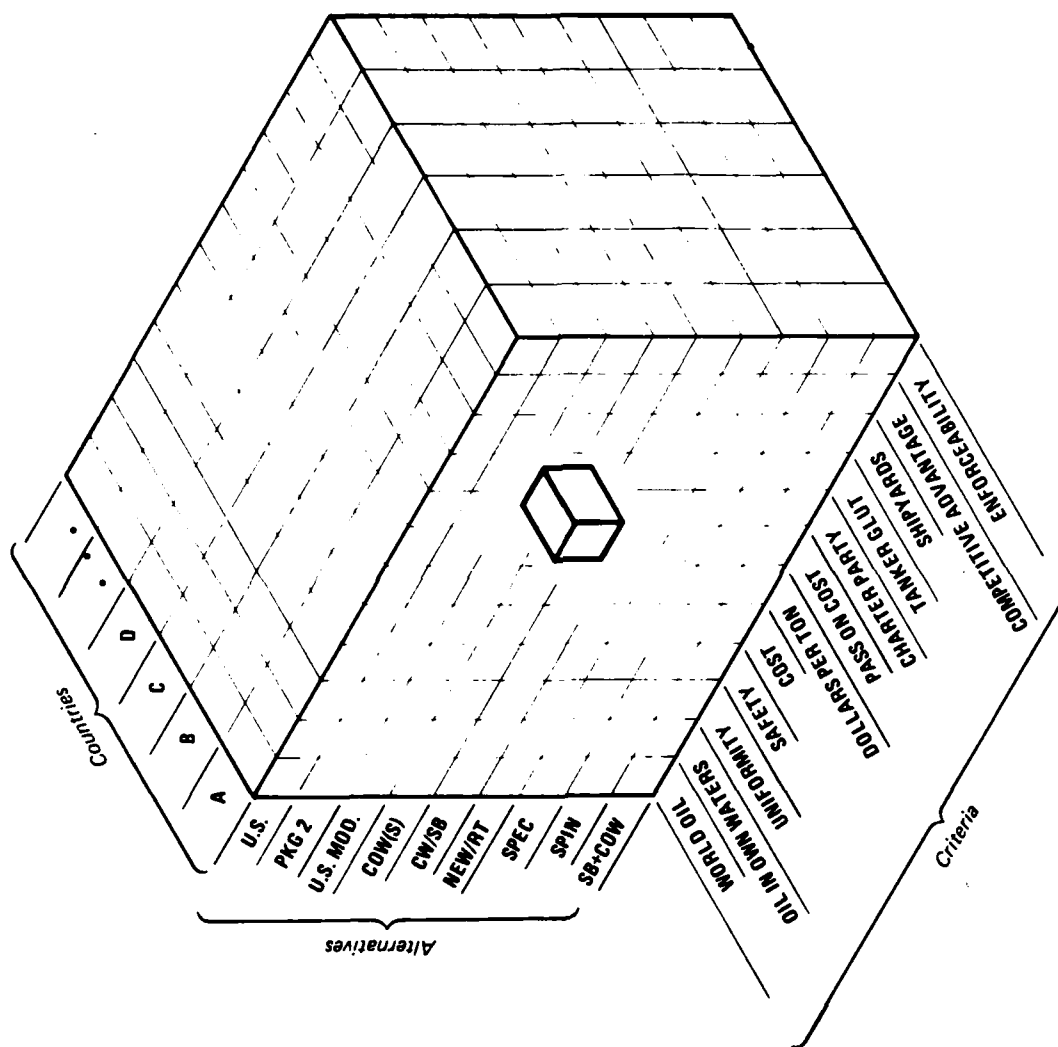


Figure 3-5
INTERNATIONAL TANKER SAFETY AND POLLUTION PREVENTION NEGOTIATION

(Note this model construction is a slight departure from the clinical art approach.) The improved value weights were generated by having Coast Guard representatives enter into bilateral discussions with representatives of the other nations to find out what issues they found particularly critical in preparing for the negotiation. In addition to gathering these value weights, the Coast Guard representatives also queried these representatives about alternatives that their countries were considering for inclusion in potential treaties. Finally, the Coast Guard representatives worked with DDI decision analysts to structure new alternatives by using the criterion of Pareto optimality. (Pareto optimal alternatives are those which enhance the position of some parties without hurting others.) However, with so many nations participating in the negotiation, this was a particularly difficult task that proved minimally successful. At the end of the second iteration the two new oil models and the new value weights for each country were used to evaluate the new potential treaties. The Coast Guard representatives examined the proposed treaties to determine which of them might be most attractive across the broad spectrum of countries involved in the negotiation.

During the third iteration, the Coast Guard communicated the results of its analyses to various U.S. interest groups such as environmentalist and industrial representatives. Feedback from these interest groups provided the Coast Guard representatives information that was useful for fine tuning the value weights of the United States and of the other countries. In addition, this communication provided feedback on the relative attractiveness of the alternatives in terms of the twelve criteria being used. As a result of this decision-analytic preparation, the negotiation team was able to concentrate on the tactics involved in the negotiation and was not surprised by "new considerations" during the negotiation.

3.2.3 Factory design decision - The final example of the clinical art approach to decision analysis is an architectural design of a factory. The approach taken in this application was to develop a set of relatively independent "building blocks" for a manufacturing facility. Twenty building blocks, which are essentially operational variables, were defined as shown in Figure 3-6. The building blocks were defined carefully to minimize the interdependence among them so that the relative costs and benefits for discrete levels of performance on each building block or variable could be estimated and a cost-benefit analysis done. In general, the levels of performance on these variables were improvements of some existing capability for that variable. The improvements had to do with such things as automation, the quality/reliability of the machinery, centralization (for example, number of sites in the factory for a given activity), and the general organization of the facility. One specific variable, however, was associated with whether the company would continue to rely on other companies for this service or would include it in its own capability.

All of these performance levels were developed with the aid of decision analysts. When work was begun, an actual design for the factory had been developed by representatives of the company and its architectural and engineering consultants. The team of decision analysts and experts/decision makers began by disaggregating this design into the variables and then pushing the designed capability for each variable to more advanced and less advanced levels. Many of the levels for these variables were options which had never been considered in an open forum by the decision makers, but which had been contemplated by individual representatives on the design task force. In addition to the decision analysts, this task force included R&D personnel, operators, engineers, management representatives, and the architectural and engineering consultants.

<u>Variable</u>	<u>Benefit</u>				<u>Wt.</u>	<u>Cost</u>			
	1	2	3	4		1	2	3	4
PLANT CONTROL SYSTEM	0	79	100		24	4	5	7	
STORAGE AND DELIVERY	0	0	100		2	1	3	11	
RECEIVING	0	14	100		7	0	3	5	
CONDITIONING	0	100	100		1	2	2	2	
BLENDING	0	73	93	100	83	2	6	7	17
PREPARATION	0	100	100		43	2	3	4	
REMOVAL	0	100			47	1	4		
REDRYING	0	0	100		23	1	1	1	
BLENDING	100	0	0	100	1	3	3	3	5
CUTTING	0	62	100		26	3	3	4	
DRYING	0	100			25	3	6		
ADD-ONS	0	40	67	100	15	1	1	1	1
APPLICATION	100	0			2	1	7		
STORAGE	0	100	100		3	7	7	10	
PACKING LAYOUT	0	100			17	2	3		
WASTE HANDLING	100	40	0		5	0	0	1	
RECLAIM	0	100			1	2	3		
SHIPPING	0	50	63	100	8	0	2	3	5
SUPPLIES	0	71	86	100	7	1	1	2	5
W.T.S.	0	38	100		52	8	9	15	

Figure 3-6
ARCHITECTURAL DESIGN OF A FACTORY

In the first iteration of the analysis, only one quantitative scale for benefit and a scale for investment cost were used. Included in the benefit scale were four factors: operational cost savings, long-term flexibility, operational flexibility, and product quality. The initial analysis demonstrated (1) what the final product of the analysis would look like, (2) that the definitions of variables and levels within the variables were sufficiently independent, and (3) that the four benefit attributes should be explicitly analyzed, and then combined by using appropriate value weights. The most useful product of this analysis is the locus of cost-effective factories as displayed in Figure 3-7. The computer prints out the most cost-effective factories at any cost or benefit in either graphic or tabular form. This printout is used initially to challenge the costs and benefits as an elicitation aid.

The second iteration began by defining the four benefit scales for operational cost savings, long-term flexibility, operational flexibility, and product quality for the levels of performance on all twenty variables. The initial inclinations of the decision analysts on this project were to develop all four benefit scales in dollars, so that they matched the cost scale. The reason was that one of the four attributes of benefit, operational cost savings, was already in dollars. This would require the costing out of the other three attributes in terms of the dollars that improvements in each of those attributes was worth to the company. The decision maker's experience was that this explicit representation of dollars would result in only operational cost savings being used as the ultimate benefit factor. So he preferred using a 0-to-100 scale for benefit rather than explicit dollars. The benefit numbers in Figure 3-6 represent this iteration. Note that the four benefit scales and the value weights could be used with the operational cost savings data to convert the overall benefit scale to a dollar scale.

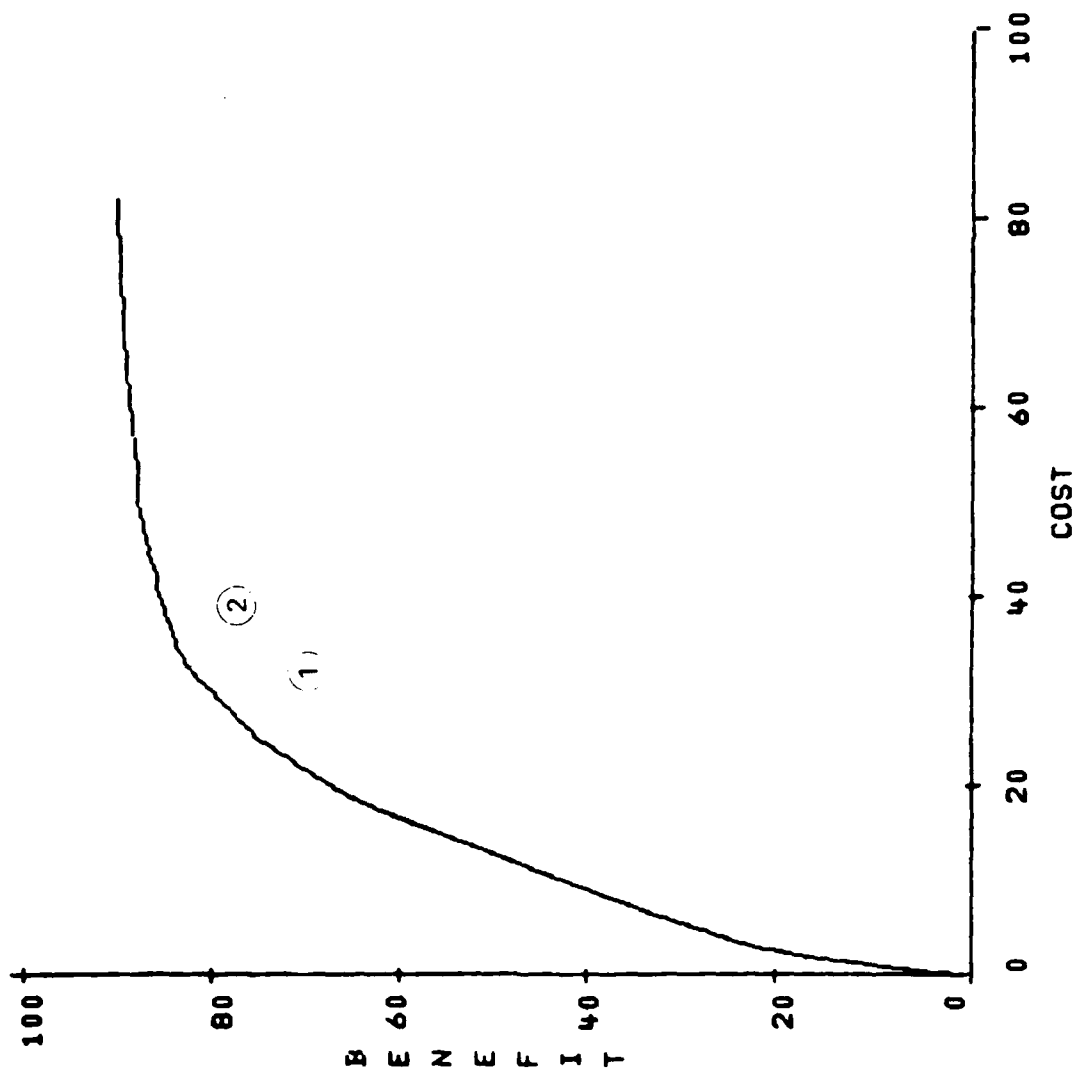


Figure 3-7
LOCUS OF COST-EFFECTIVE FACTORIES

Figure 3-7 represents the final locus of cost-effective factories. Besides the new design options that were uncovered, and the cost-beneficial locus of the factories implied from the quantitative analysis, the decision-analytic effort resulted in significantly improved communications among all representatives on the task force in terms of the ultimate goals and needs of the company for the new factory. The original design of the factory is represented by the circled 1 in Figure 3-7. The decision maker felt that this comparison of the original design with the locus of cost-effective factories was an unfair comparison because several of the new levels considered in the quantitative analysis were so attractive that they would have been included in the initial design had they been known. So, the decision maker was asked to identify those options which would have been included in the initial design, and this factory is represented by the circled 2 in Figure 3-7. Note that in both cases, the quantitative analysis identifies improved factories, and the decision maker thoroughly agreed that the analysis was correct after examining these factories.

3.2.4 Summary - This concludes the illustration of the engineering science and clinical art approaches to decision analysis. It is important to note that these two approaches are meant to be mutually exclusive, but not collectively exhaustive. The engineering science approach focuses heavily on the process underlying the decision. The clinical art approach accepts constraints (whether legal, political, or otherwise) placed upon the prescriptive decision-analytic paradigm; this approach attempts to elicit and describe the critical issues facing the decision maker and to provide a thorough examination of the available options.

There are clearly many intermediary approaches to decision analysis; the two discussed here, engineering science and clinical art, represent extremes. The purpose

of this paper and the topic of the next section is to learn more about the practice of decision analysis by examining these two extremes.

4.0 DISCUSSION

The highlights of the examples illustrating the engineering science and clinical art approaches have prepared us for a discussion of the situations in which one approach would be more appropriate than the other and of the effects the chosen approach might have upon any decision being considered. In this section, we first specify the types of decisions--in terms of the characteristics of the decision maker, the decision topic and the constraints--that would be analyzed most usefully from either an engineering science or a clinical art point of view. Next, we touch upon some of the implications of each approach for the decision maker, and discuss the decision-making process and how each approach seems to mesh with that process from a decision maker's point of view. Finally, we present the decision analyst's decision, that is, the selection of either the engineering science or the clinical art approach for a particular decision situation and what uncertainties seem to be critical to that selection.

Before discussing these four topics, however, we would like to emphasize again that the decision analyst's purpose is to improve the decision maker's decision. The most effective way to make this improvement is to provide the decision maker with more insight and understanding into his/her decision via the analysis that is done. Recall that the structure provided by, and the numbers used in, the analysis are the principal means by which this insight and understanding are obtained; however, the decision maker has to be involved in the analysis. Howard has called this involvement the "immersion value" of the analysis; and, clearly, without immersion, there is very little gain in insight or understanding.

4.1 Engineering Science versus Clinical Art: A Characterization of When Each is Most Attractive

In characterizing which type of decision analysis--engineering science or clinical art--would be more attractive for a particular decision situation, three pertinent aspects are the decision maker, the decision, and the constraints. When considering the engineering science versus clinical art dichotomy, the autonomy and the analytical knowledge and beliefs of the decision maker are relevant. The aspects of the actual decision that distinguish between these two extremes are alternatives, values, and the decision process. Finally, the time constraints faced by the decision maker and the decision analyst team are important.

Table 4-1 highlights these aspects of the decision. Also described in this table is the best possible fulfillment of each aspect for both the engineering science and the clinical art approaches. From the information in Table 4-1 and the examples presented earlier, it appears that the two most critical aspects for distinguishing between engineering science and clinical art are the authority of the decision maker and the process by which the alternatives of the decision are related to the outcomes.

Since the main goal of the decision analysis is to provide the decision maker with insight and understanding into the problem at hand, an autonomous decision maker, receptive and willing to participate in an analytic process, would clearly be best served by the engineering science approach. On the other hand, a hierarchically organized decision-making body is potentially best served by the clinical art approach. By "hierarchically organized," we mean a pseudo-decision maker who has the responsibility to examine all issues involved in the decision, and to write a recommendation and the justification for it. This recommendation and justification must then be transmitted either

		<i>Engineering Science</i>	<i>Clinical Art</i>
DECISION MAKER	AUTHORITY	AUTONOMOUS	COMMITTEE/ HIERARCHICAL STRUCTURE
	ANALYTIC BELIEFS/ KNOWLEDGE	TRUSTING/ SOPHISTICATED	SKEPTICAL/NAIVE
	ALTERNATIVES	LIMITED NUMBER/ WELL-DEFINED	NUMEROUS/NEBULOUS
DECISION	VALUES	FEW, WELL-DEFINED PARAMETERS	NUMEROUS, EQUIVOCAL CLASSIFICATIONS
	PROCESS	ACCEPTED THEORIES/ DIVIDED PRACTICAL EXPERTS	ACCEPTED SUB THEORIES/ PRACTICAL EXPERTS
CONSTRAINTS	TIME	MONTHS/YEARS	WEEKS/MONTHS

Table 4-1
 CHARACTERIZATION OF THE
 ENGINEERING SCIENCE AND CLINICAL ART APPROACHES

verbally or in writing through one or more higher level decision makers. To ensure the immersion of the higher level decision makers, it seems that the simple, readily discernible structure of the clinical art approach is most effective. This is especially true when the decision makers are either skeptical of, or naive about, complex mathematical models.

Another aspect that has a major impact on the difference in effect of the engineering science and clinical art approaches is the process that will be impacted by the decision. The complex mathematical models of the engineering science approach seem to be the accepted way to deal with a decision process (1) when the process is so complex that the experts involved only vaguely understand it and have difficulty explaining it, and (2) when there are accepted theories applicable to the process, such as microeconomics. Good examples of the appropriateness of the engineering science approach are those presented in Section 3.1. On the other hand, when there are practical experts whose understanding of the process is accepted and in many cases felt to be superior to theoretical models, the clinical art approach--incorporating all of the inputs from practical experts--works extremely well.

In addition, it is easier to develop a complex mathematical model of a decision process when there are only a few well-defined decision alternatives and only a few well-defined value parameters. So, as the number of alternatives and value parameters increases, and if there are many equally good classifications or descriptions of the value parameters, the clinical art approach becomes more and more attractive. Finally, because of the simplicity of the clinical art approach, it is favored when severe time constraints (on the order of weeks and months) are placed on the decision maker.

4.2 The Implications of the Engineering Science and Clinical Art Approaches

The implications of each approach in terms of quality, time, experts, iterations, and decision maker/decision analyst contact, are summarized in Table 4-2. First, the quality of the decision-analytic model is highlighted. The engineering science approach begins by developing a fairly complex, often dynamic, deterministic model of the decision process. In the prototype and production phases of the analysis, this model is improved, made probabilistic, and tested and validated to the extent possible. Clearly, a major part of the value of the engineering science type of analysis depends upon whether the model is a fairly good approximation of reality.

On the other hand, the clinical art approach is generally restricted to value judgments during the first iteration. Successive iterations may introduce scenarios (and hence probabilities) as well as increase the number and quality of the value judgments made. The goal of this approach is not to produce a realistic model, but simply to develop a systematic means for the decision maker and his/her experts to address their problem--a means that eliminates as much confusion as possible while maintaining simplicity.

The elicitation process used by the clinical art decision analyst is in many ways as important, if not more important than the structure that is developed. Rather than being satisfied with one set of numbers for the simple structure that has been developed, the decision analyst triangulates on these numbers by eliciting them several different ways. This triangulation is a search for inconsistencies; if any are uncovered, they are used to probe the decision maker's thought processes to see whether elements of the

	<i>Engineering Science</i>	<i>Clinical Art</i>
QUALITY	PILOT	VALUE JUDGMENTS
	FINAL	VALUE JUDGMENTS/ SCENARIOS
	VALIDITY	"POOR"
TIME	PILOT	DAYS
	FINAL	WEEKS/MONTHS
EXPERTS	PROCESS	PRACTICAL
ITERATIONS	2-3	2-10
D.M. AND D.A. CONTACT	50/50	80/20

Table 4-2
 IMPLICATIONS OF THE
 ENGINEERING SCIENCE AND CLINICAL ART APPROACHES

structure have been left out or have been misvalued. The several iterations and the triangulation on value judgments promote systematic thought, discussion, and dialogue. The decision analyst who uses the clinical art approach and does not employ triangulation will not provide as much insight and understanding as the one who does.

The second factor to be considered for each type of analysis is the time required: the length of time for the pilot and the final iteration of each approach differs significantly because of the complexity of one and the simplicity of the other.

The third factor concerns the major distinction between the type of experts called upon by the decision maker and decision analyst in each type of analysis. As mentioned earlier, the engineering science approach builds a complex model of the decision process. Because these models are typically based upon some sort of theory (economic, engineering, and the like), the decision maker and the decision analyst work with what we will call "process" experts, that is, experts on the theories about the underlying decision process. In contrast, the clinical art approach makes use of practical expertise about the decision process. Its simple structural models do not attempt to mimic the decision process. But they do attempt to separate and classify the many aspects of the decision process and to determine which of those aspects discriminates most effectively among the alternatives open to the decision maker. In this way, the clinical art approach generates numerous value assessments that require practical expertise rather than theoretical expertise.

The fourth factor is iterations, and there is a slight difference in the number of iterations each approach generates. The engineering science approach documented by

Howard dictates that there be a pilot phase, a prototype phase, and a production phase. While this is standard operating procedure, it is clearly recognized that the decision analysis may be terminated at either the pilot or prototype phase if the best alternative has been identified at that point. With the clinical art approach, many smaller iterations generally are undertaken by the decision analyst. These iterations are often not so well-defined, but nonetheless, changes in the structural model, the scope of the analysis, and so forth are made as the analysis proceeds.

Finally, the amount of contact between the decision-making team and the decision-analytic team differs: in an engineering science analysis, the decision analysis team spends 30 to 50% of its time interacting with the decision-making team and the rest developing the model on the computer. In a clinical art analysis, the decision analysis team interacts considerably more with the decision-making team, generally about 80% of the time.

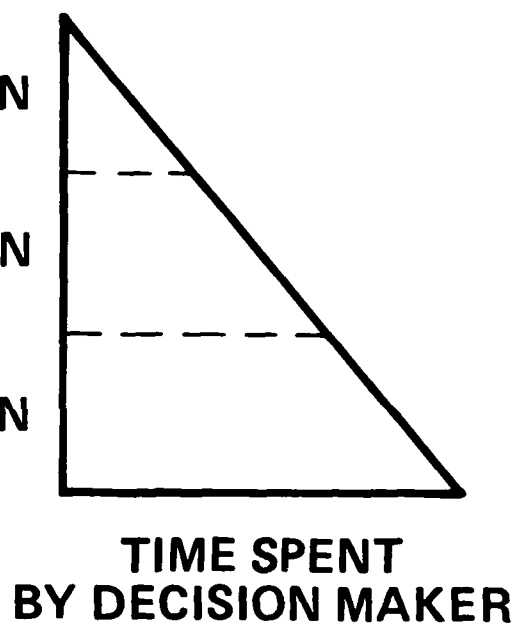
4.3 Decision-Making Process

Much has been written about the process decision makers put themselves through when wrestling with a decision problem. (Note that this is a decision-making process and is different from the decision process that is the focus of the engineering science approach. To differentiate between them, the former is always referred to as the "decision-making process.") From this literature and our experience, we have abstracted three distinct phases that any decision maker might go through in terms of evaluating the alternatives for a particular decision. Figure 4-1 illustrates the decision-making process. The area corresponding to each phase of the process is meant to be a rough approximation of the amount of time spent by the decision maker in each phase.

DECISION RECOGNITION

DECISION DEFINITION

DECISION SOLUTION



**Figure 4-1
DECISION-MAKING PROCESS**

The first phase is one of recognition, during which the decision maker realizes that taking some action might be preferable to letting things proceed as they are. Part of this recognition is realizing that something can be done to change the status quo; that is, more than one alternative is available. The decision maker seldom spends much time in this phase.

The definition of the decision is the next phase of the decision-making process. It is here that the decision maker begins to define plausible alternatives, value parameters that may differentiate among the alternatives, and other factors that impact upon the decision. This is a formulation phase; and, typically, more time is spent here than in the recognition phase. We often think not enough time is spent by the decision maker in this definition phase. If more high-quality time were spent on definition, the decision analysis paradigm might not be able to yield as much insight and understanding as practice has shown that it does. All too often, the decision maker jumps quickly into the information-gathering mode of the next phase when thoughtful consideration would have greater payoffs.

Finally, during the decision-solution phase, the decision maker reaches a decision, using whatever procedures he or she chooses. The greatest percentage of time is spent in the decision-solution phase, and new alternatives and value dimensions are discovered here. Too frequently, an excessive amount of this time is spent gathering information rather than examining one's own knowledge.

The engineering science approach to decision analysis is one of modeling. As mentioned earlier, the model is the link between the alternatives and the outcomes, which are converted into the values of the decision maker. Because of this focus, it seems that the major portion of the decision

analyst's time is spent on this model and hence on the solution phase of the decision-making process. Figure 4-2 represents the decision analyst's augmentation of the decision maker's time during this process.

With the clinical art approach, much of the decision analyst's time is spent (1) probing the decision maker for new alternatives (as in the architectural factory design), (2) probing for value attributes that the decision maker had not specified, and (3) investigating new ways to classify the value attributes that have been specified. In most respects, the decision process is downplayed. For this reason, the clinical art analyst spends more time with the decision maker during the definition phase than does the engineering science analyst. Also, the clinical art analyst spends much less time with the decision maker during the solution phase of the process, as illustrated in Figure 4-3.

4.4 The Decision Analyst's Decision

If a decision analyst were deciding which approach to use, engineering science or clinical art, that decision would look something like the illustration in Figure 4-4. However, these are not the only two options open to the analyst; rather, they are two extremes. Very few analysts practice one extreme to the exclusion of everything else. However, for this paper we assume that the decision analyst has only two choices for any analysis, the engineering science approach or the clinical art approach.

The first uncertainty the analyst faces in choosing an approach involves the agreement between the best decision, as represented by the beliefs and judgments of the decision maker, and the result of the analysis. For instance, for many types of decisions, the engineering science approach is much more likely to produce a result more consistent with

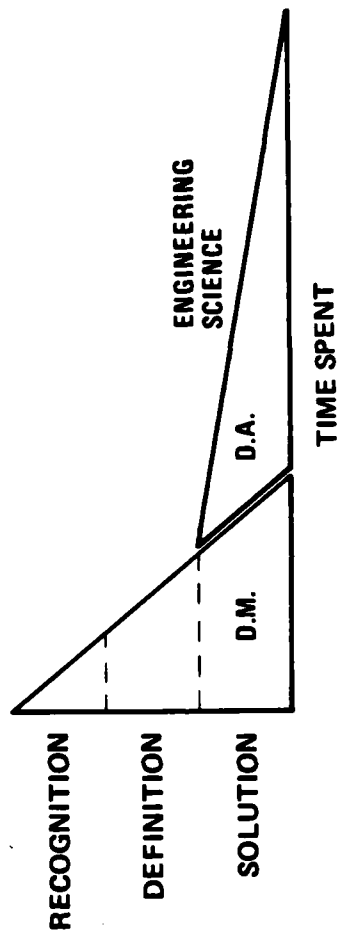


Figure 4-2
DECISION-MAKING PROCESS: ENGINEERING SCIENCE

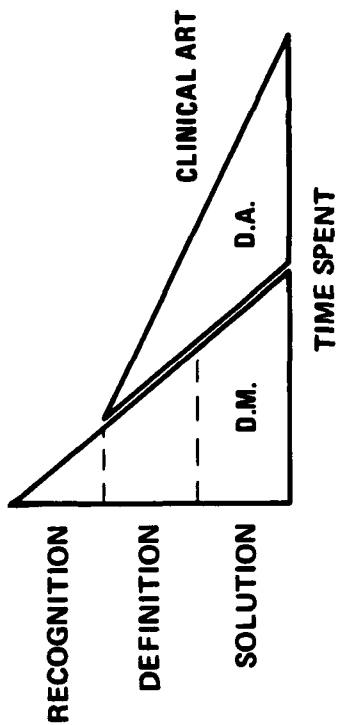


Figure 4-3
DECISION-MAKING PROCESS: CLINICAL ART

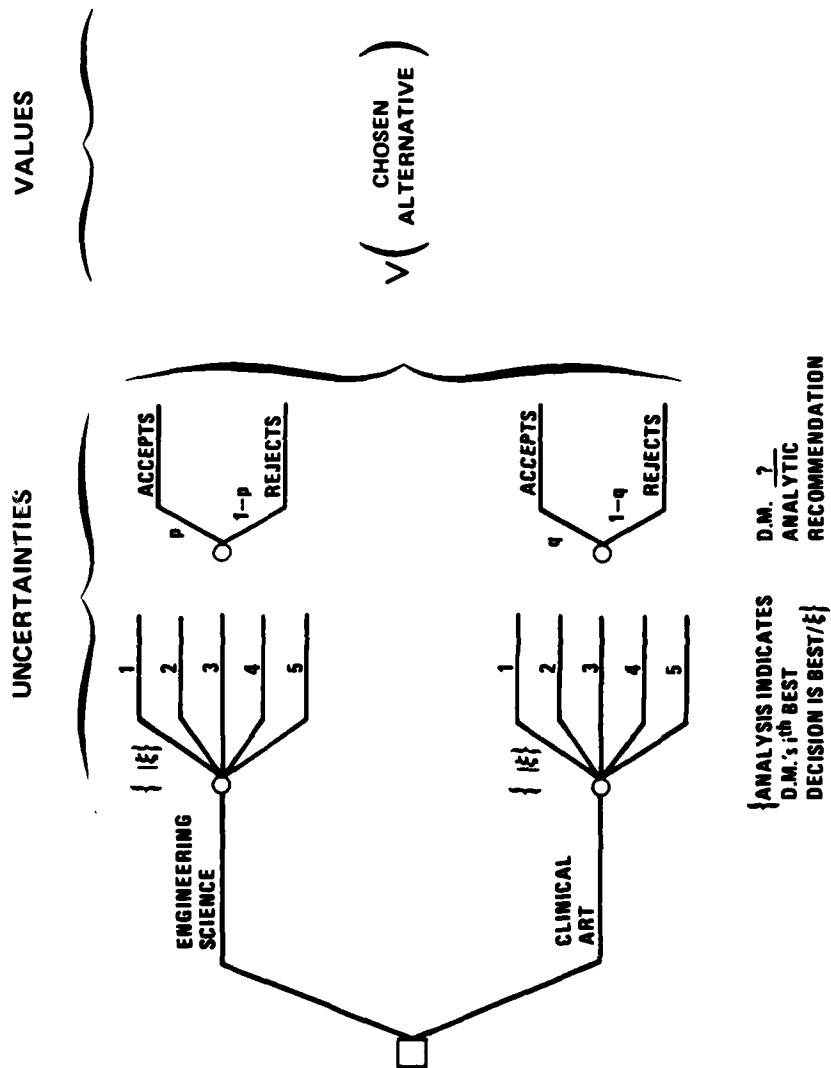


Figure 4-4
DECISION ANALYST'S DECISION

the decision maker's beliefs than is the clinical art approach. The best example is a decision situation in which the participants have very little practical expertise but substantial theoretical expertise about the particular decision process. On the other hand, for certain decisions, the best outcomes are partially determined by how long it takes to make a decision. The factory design decision discussed earlier is a good example: there was an opportunity cost of \$5 million per month to the corporation until this factory was built. In this case, a good early decision is much preferred to a good late decision. It is also possible that the decision analyst using the engineering science approach could, in some situations, get so absorbed in developing the complex process model that an error of the third kind, as attributed to John Tukey (1968) by Raiffa, is made. That is, the wrong decision is analyzed. (This is a problem faced by any decision analyst, independent of the approach being used.)

The second uncertainty faced by the decision analyst in evaluating the two analytic approaches is the probability that the decision maker will either accept or reject the result of the analysis. For exposition purposes, we will assume that should the analysis be rejected, the decision maker would opt for the alternative that was intuitively favored before the analysis began. However, any decision maker who agrees to undertake a decision analysis will likely have many preconceptions changed; and, therefore, while the recommendation of the analysis may be rejected, the decision maker may opt for an alternative that otherwise would not have been chosen without the analysis. In thinking about this uncertainty, the analyst must measure the autonomy, the analytical knowledge, and the beliefs of the decision maker. In a hierarchical decision-making organization, very little immersion of the highest level decision makers would result from using the engineering science approach. On the

other hand, decision makers with a high level of analytical knowledge or analytical trust are more suited to the engineering science approach.

Finally, the evaluation of the decision-analysis alternatives must be concluded with a value model that relates the relative values of the decision makers alternatives to each potential path through the decision tree. The values of these paths through the decision tree, however, are completely independent of any discussion presented in this paper.

5.0 CONCLUSIONS

The conclusions to be drawn from this paper are the following:

1. There is a significant difference between the extreme approaches to applying decision analysis. The engineering science approach focuses on a complex mathematical model to describe the interface between the decision maker's alternatives and his/her values. In contrast, the clinical art approach attempts to build a structural model that will distinguish among the alternatives available to the decision maker as clearly as possible so that any reasons for choosing one alternative over another may be clearly identified and communicated.
2. The engineering science approach seems to work very well with well-defined decisions in which the process connecting the alternatives with the decision maker's values is complex enough to be poorly understood by practical experts but well-defined enough so that theoretical experts are justified in their explanations of it. In addition, the decision maker must be willing to trust these analytical models sufficiently, so that they can provide appropriate insight into and understanding of the process that they are depicting.
3. The clinical art approach works extremely well when there is a hierarchical decision-making body, each level of which is taking an active interest in the decision being made and not acting as a rubber stamp. Also, the clinical art approach

is most applicable when there are many well-respected practical experts who have the confidence of the decision maker and who can be relied upon to accurately distinguish, in their areas of expertise, among the alternatives faced by the decision maker.

4. The simplicity of the clinical art approach makes it possible for the decision analyst to interact with the decision maker during the definition phase of the decision-making process. In fact, some decision analysts might find it attractive to use both approaches on a particular problem. That is, the clinical art approach might be used to assist the decision maker during the problem-definition phase, and the engineering science approach might be used to assist the decision maker during the problem-solution phase.

In summary, there is a substantial difference between the two extreme approaches of applying decision analysis, and the situations in which each might be useful also differ significantly. The philosophy behind each approach is best summarized by quotes from two well-known scientists. Alfred North Whitehead once said scientists should "seek simplicity and then distrust it." This philosophy seems to be characteristic of practitioners who use the clinical art approach. That is, a simple structure is formulated; many different ways of eliciting the numerical representations for that structure are investigated so that inconsistencies can be uncovered and examined to increase understanding. Finally, this structure is used to convey to the decision maker(s) the major differences among the alternatives with the reliance being on the information transmitted rather than on the numerical scores. Thus, in the ultimate sense, the numerical scores are not the bottom line.

Albert Einstein once said "everything should be made as simple as possible but not simpler." This is clearly the philosophy of the engineering science school because their iterative approach to modeling the decision process is one of "separating the wheat from the chaff," that is, modeling only those things relevant to the decision and ignoring the others. On the other hand, the ultimate model is quite complex and as descriptive of reality as possible, given the situation.

But as every decision analyst knows, it is the decision maker who is the judge of the decision analyst's work, and the decision maker for whom the analysis is done.

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